The TEAM Model for Evaluating Alternative Adaptation Strategies

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Abstract[1]

Advances in the scientific literature have focused attention on the need to develop adaptation strategies to reduce the risks, and take advantage of the opportunities, posed by climate change and climate variability. Adaptation needs to be considered as part of any response plan. But appropriate adaptive responses will vary across different geographic regions since the potential consequences of climate change and variability for human and natural systems will vary regionally in scope and severity. The assessment of consequences and selection of appropriate adaptation strategies is a complex challenge for regional and local decision makers. To aid in these assessments, the U.S. EPA developed a decision support software system called the Tool for Environmental Assessment and Management (TEAM) that employs a multi-criteria approach for evaluating actions to address climate change impacts. Applications of TEAM have revealed some strengths of this tool: (1) transparency of the methodology used in TEAM is important, particularly to international audiences; (2) the structure encourages users to consider strategies and attributes from an array of disciplines, which leads to more effective outcomes; (3) the ability to consider and understand tradeoffs of noncomparable attributes is essential to good decision making; and (4) TEAM fosters communication and consensus among participants in the decision making process, in particular through the use of visual display features and sensitivity analyses.

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1 Introduction

Management problems are often complex because of the need to consider multiple objectives, the need to formulate and consider different aspects of a problem, and the

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need to assess the importance and relevance of these aspects in some consistent way. As noted by Zeleny (1982):

> "decision making is ultimately the most difficult (and potentially the most rewarding) activity because a 'model' of any reasonable richness will return multiple criteria, forcing us to choose not only among the possible courses of action but also among the means of evaluating such actions."

Supporting the decision making process calls for a systematic approach to making choices and providing useful insights in complex situations.

Climate change is an example of a particularly difficult and complex problem facing decision makers today. This environmental problem provides an excellent illustration of the potential complexity of a decision-making process because of the multi-disciplinary nature of the issue, uncertainties about the potential magnitude, timing and effects of climate change, uncertainties about the effectiveness of different courses of action to adequately address the potential impacts, and the existence of many alternative societal problems competing for scarce resources that could be used to address concerns about climate change (Smith and Chu 1994, Scheraga and Julius 1995).

The U.S. Environmental Protection Agency has developed a decision support software system called the Tool for Environmental Assessment and Management (TEAM), to assist decision makers trying to assess risks posed by climate change and to select adaptive responses. TEAM employs a multi-criteria approach for evaluating actions to address climate change impacts to water resources, coastal zones, and agriculture.

2 Evolution of TEAM

The historic Framework Convention on Climate Change (FCCC) was signed by 154 countries in June 1992. The ultimate objective of this Convention, as proclaimed in Article 2, is to prevent dangerous anthropogenic interference in the climate system, to achieve this within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

Two different but complementary mechanisms exist for fulfilling the goals of the Convention: *mitigation* of greenhouse gas emissions and *adaptation* to the potential effects of climate change. Mitigation refers to policies intended to reduce anthropogenic emissions of greenhouse gases which contribute to global climate change. Adaptive actions are those responses taken to reduce damages to human and natural systems resulting from climate change.

Anticipatory adaptation refers specifically to those actions taken before the effects of climate change are apparent. These measures contrast with actions taken in *reaction* to the impacts of climate change. Often, anticipatory investments can be completed at lower costs than comparable actions that are taken when impacts are observable. Also, delaying action may render some strategies ineffective or impossible to implement if long lead times are required. Failure to anticipate particular climate impacts may cause irreversible damages to natural systems and the loss of unique cultural resources. The development of TEAM was undertaken to help decision makers consider alternative anticipatory adaptation strategies for reducing the risks posed by climate change.

3 Features of TEAM Oriented to Decision Makers

3.1 Steps of TEAM Software

Each step in TEAM is designed to provide easy management of information and the ability to manipulate presentation of information while investigating tradeoffs. In the first step of TEAM, the geographic region is identified, and the resource (e.g., water basin, agricultural system, coastal zone) is characterized according to its vulnerabilities to climate change and other stressors. The appropriate geographic scale will depend on the type of resource being evaluated and the classification of the resource or site. TEAM helps establish the appropriate scale by guiding the user through a series of questions to define the analysis and evaluate the facts.

The second step is to specify the actions to be considered for addressing the identified vulnerable system or resource. The types of actions that may be specified range in nature from action oriented (e.g., building sea walls), to planning oriented (e.g., legal or regulatory changes such as zoning rules and building codes). The system provides a list of suggested actions within each of these categories, and allows for additions or modifications to the list.

The third step, selection of evaluation criteria, is central to this tool. TEAM provides suggested criteria, and allows for additions to be made to the list. This structure encourages consideration of a broad spectrum of factors that may be important to a decision, ensuring comprehensiveness to the decision making process.

Prior to scoring the strategies (step four), the user is encouraged to make an explicit decision about the time horizon over which the assessment will be made and enters that time horizon into TEAM. The user chooses the time horizon that is appropriate for the particular planning decision and the choice is displayed throughout the scoring process to ensure consistency in evaluation.

The fourth step is evaluating and scoring the selected actions. This step entails comparing options against the criteria selected to assess the performance of each. This step elicits judgements about the performance of options and promotes articulation of the reasoning behind judgements. The system encourages qualitative assessments of performance, but allows for quantitative comparisons to be made where that data exist. Scoring is done based on the user’s evaluation of the effectiveness of a given strategy in meeting goals as expressed through the criteria selected. The scores entered are based on a relative comparison of specified strategies, and the scoring categories of “excellent,” “good,” “fair,” and “poor” may vary from criterion to criterion.

The final step, assessing results, promotes consideration of the consequences of each action under review. TEAM provides alternative presentations of the information through different visual displays to aid the investigation of consequences and tradeoffs implied by choosing particular actions. Each action may be compared against the other for the criteria selected. The criteria are not aggregated to provide a single index of performance for each action. In this way, clear or subtle differences in alternative courses of actions for each criterion may be understood.

TEAM has six different types of visual displays from which to choose to foster further exploration of the data, which may lead to insights that a single display would fail to reveal (see Smith et al. 1995 for a description of each visual display). Sensitivity analyses complement this exploration and understanding of priorities and tradeoffs. These sensitivity analyses may be performed by going back to previous stages of the process and changing inputs (criteria, strategies, scores, absolute data such as costs), or selecting different assumptions under which to conduct the analyses and modifying the inputs accordingly, or simply modifying weights on the criteria to reflect judgements of their relative importance. Uncertainty is addressed through the ability to conduct sensitivity analyses on the uncertain variables and assess the effect on the overall results.

3.2 Limitations of TEAM

One limitation of TEAM is that the user can manipulate the data to produce a desirable outcome. There are some checks within TEAM to prevent this (e.g., displaying weights when a user has applied them to criteria), but they may not be adequate to prevent such manipulation. Also, the qualitative scoring is only as good as the user’s knowledge of the performance of different strategies. Group participation may help the quality of the analysis and this approach to the use of TEAM is recommended. Finally, TEAM has no check on the internal consistency of the user’s inputs with respect to data or scoring.

4 Applications of TEAM and insights gained

In March 1995, seven case studies were conducted in collaboration with colleagues at the University of Cairo's Faculty of Agriculture, and at the University of Alexandria's Department of Environmental Studies. These case studies were funded as part of the United States Country Studies Program to assist developing countries in assessing their vulnerability to climate change and possible adaptation options. In 1997, several researchers from the University of Cairo were able to visit the United States to conduct further analysis that built on one of the case studies performed in 1995. Because the two phases of this case study reveal the usefulness of TEAM in a decision process, from the formative stage of the problem to making preliminary recommendations to the government of Egypt, it is the focus of discussion below. The first phase of the case study is an assessment of the vulnerability of wheat production in the Nile Delta area. The second phase is an assessment of a broader range of alternative crops and rotation practices using historical data and information gathered from crop models.

4.1 Phase I - Wheat Production in the Nile Delta Area

The site for the study was the Nile Delta area which encompasses 22,000 square kilometers on the Mediterranean coast. Although this area accounts for only 3% of the country's land area, it provides 45% of the nation's cultivated land. In 1984 and 1987, agriculture accounted for about 20% of Egypt's gross domestic product (Hansen 1991, Strzepek 1995). Egypt's agricultural water supply comes entirely from irrigation and the only source for water is the Nile River. Agricultural uses consume 80% of the water budget (Shahin 1985, Strzepek et al. 1995).

Climate change is likely to have a significant effect on the supply of water available for irrigation and other uses. Runoff may decrease as a result of higher evaporation and changes in precipitation. These changes, along with increased evapotranspiration under a warmer climate, will increase water losses in the fields and during storage and transport processes. Increased climate variability (drought, heat waves) could pose an additional threat to agricultural production (Strzepek et al. 1995).

The Egyptian agricultural year is composed of three crop seasons. These seasons and their crops are:

- *winter season:* wheat and barley, berseem and lentils, winter onions, and vegetables, planted between October and December and harvested between April and June;
- *summer season:* cotton, rice, maize, sorghum, sesame, groundnuts, summer onions, and vegetables, with the growing season starting in March and ending in November;
- *late summer season:* rice, sorghum, berseem, and some vegetables, with planting times overlapping the summer growing season, necessitating different years for plantings of summer and late summer crops.

The crop selected as the focus of this initial study was wheat. Wheat is widely grown in the Nile Delta area and is important as a component of the Egyptian diet. Production is viewed as critical to maintaining Egypt's food security. The combination of projected increases in the demand for wheat and the sensitivity of wheat productivity to changes in climate are a cause for concern. If, as expected, this is the trend for most agricultural commodities, the implication is that the agricultural trade balance will be affected and net imports of all agricultural commodities will increase (Fischer et al. 1988).

The three purposes of the first phase of this case study were to: provide hands-on training in the use of the methodology employed in TEAM; prepare specific applications to address climate change vulnerabilities in Egypt, and; introduce the users to a way of structuring information and results from a variety of sources and models to enable a systematic consideration and assessment of adaptation options to address identified vulnerabilities.

Three types of vulnerabilities of wheat production were identified: drought, weed, and heat stress. Among these vulnerabilities, drought was the most serious consideration in the context of potential future climate change. The categories of strategies to choose from included no anticipatory action, changing agricultural practices, switching to a new type of cultivar, switching to a new type of crop, or abandonment of agriculture in favor of an alternative use of the land. After extensive discussion, five candidate strategies were developed: two strategies consisted of changing agricultural practices, two strategies were to switch to a new cultivar, and one strategy was to take no action. They are defined more completely below:

1. *Tillage* – implement minimum tillage and change planting dates; increase government import of herbicides and conduct education programs about timing and cultivating methods.
2. *Mech* – provide government funding to import small-scale machines suitable for Egypt's geography and increase mechanization in farming.
3. *Culti1* – provide government funding for development of drought resistant wheat variety; change planting dates and use more fertilizer; modify existing seed distribution systems to aid in widespread adoption of new cultivar.
4. *Culti2* – provide government funding for development of heat- and drought-resistant wheat variety; change planting dates and use more fertilizer; modify existing seed distribution systems to aid in widespread adoption of new cultivar.
5. *No Policy Action* – no anticipatory action will be taken.

After reviewing the candidate list of attributes in TEAM, seven attributes were selected to evaluate the candidate strategies: up-front costs for implementing strategy; long-term expected net benefits; effectiveness in addressing vulnerability; farm income (yield, price, and cost of production); technical/financing feasibility; distributional impact; and food security.

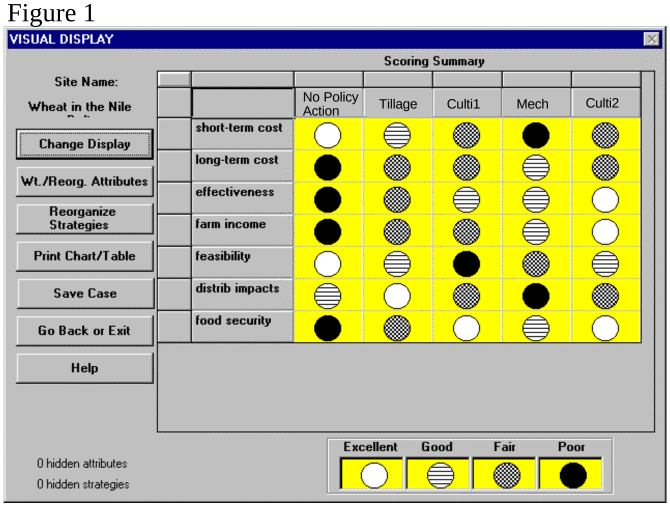
Once the selection of strategies and evaluation criteria were chosen, each strategy was compared based on the above criteria. The relative performance of the strategies are represented by the scores shown in the following table:

Table 1

	No Policy Action	**Tillage**	**Culti1**	**Mech**	**Culti2**
short-term cost	Excellent	good	fair	poor	fair
long-term cost	Poor	fair	fair	good	fair
effectiveness	Poor	fair	good	good	excellent
farm income	Poor	fair	fair	good	excellent
feasibility	Excellent	good	poor	fair	good
distrib impacts	Good	excellent	fair	poor	fair
food security	Poor	fair	excellent	good	excellent

The choice of seven attributes added to the complexity of the case because of the need to consider each one in light of the others, for all of the selected strategies. Using TEAM's bubble chart display, the two strategies "Tillage" and "Culti2" appeared to perform relatively better than the others (see Figure 1). The "No Policy Action" should only be pursued if the country had no resources available to allocate to action in the short term. However, switching to the column chart display to view the results made the judgement of the most desirable strategy much more difficult to determine (see Figure

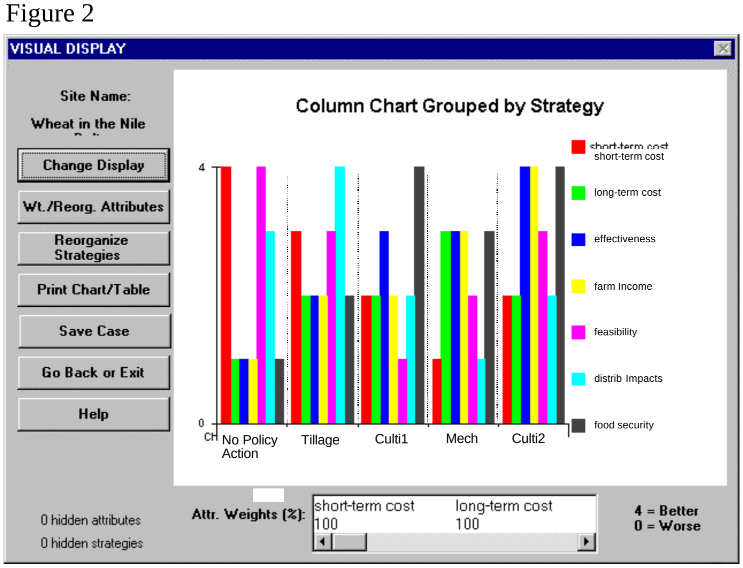
Figure 1



2). Because of this difficulty, a set of weights were selected by the participants for each of the criteria in order to reflect more strongly their priorities in decision making (see Figure 3). For example, the more important criteria received higher weights than the less important criteria, causing their performance to be emphasized visually over the less important criteria. When these weights were applied, it became more evident that "Culti2" was the best overall strategy, while "Tillage" dropped off in strength of performance.

Despite the good performance of the "Culti2" strategy, participants in the case

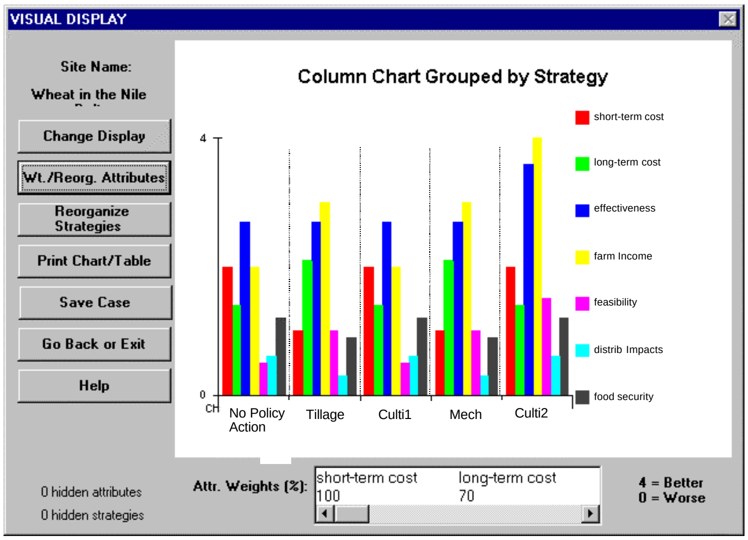
Figure 2



study raised some of the difficulties involved with implementing this strategy. These difficulties included the government's unwillingness to fund cultivar research and the possible uneven distribution of the strategy’s benefits among farmers. The strategy had limitations and required further analysis to improve the probability of its success.

As illustrated above, TEAM’s visual displays provided a means of summarizing for the participants the fairly complex evaluation information and allowed them to easily interpret the results. Sensitivity analyses in the form of application of different value

Figure 3



functions through weighting schemes were also easy to perform and evaluate.

Using TEAM in this initial phase of analysis was critical for developing a decision-oriented mindset among the researchers. Such issues as financing barriers for cultivar development were previously not the focus of concern for most members of the analytic team. The process of considering and evaluating the options above also stimulated an evolution of thought about new options. Group interactions resulted in a focused research agenda that would produce information relevant to the decision making process. Some items on the list for the next phase of analysis were: crop modeling analyses to improve understanding of the impacts of climate change on crop productivity and the effectiveness of different strategies under changed climate and growing conditions; analysis of historical data on farm income; analysis of the effect of changes in crop productivity on projected future farm income; and examination of the technical and political feasibility of the alternatives enumerated in the case study. The group recommended broadening these analyses to other possible strategies in addition to alternative wheat cultivars.

4.2 Phase II

Phase II of the analysis expanded on adaptation alternatives and crops examined. The three regions under study were the Central Delta region represented by Sakha (responsible for 60% of the national wheat production, 75% of the total maize production, and 75% of cotton production), the Middle Egypt region represented by Giza, and Upper Egypt represented by Shandaweel.

Prior to beginning Phase II of the case study, Dr. Helmy Eid conducted quantitative crop modeling which generated evidence about the direction and magnitude of productivity responses of various crops. Information on crop vulnerabilities were from model runs of COTTAM and DSSAT3[2]. Crops considered in this study were wheat, maize, cotton, rice and sugar cane. Dr. Eid also gathered data on historical patterns of crop prices and crop productivity. These sources of data were combined to construct farm incomes under different scenarios[3]. These quantitative results were input into TEAM to examine key trade-offs and interactions among alternative agricultural strategies that were feasible for the Egyptian agricultural economy under changed climatic conditions. The results provided quantitative evidence of crop productivity and vulnerability that differed from expert judgement used in the first phase of the case study.

The decision criteria chosen for the analysis were agricultural income, food security, industry/employment, food culture, water demand and chemical usage. The final list of strategies examined were combinations of different crops and alterations in cropping patterns, alterations in types of cultivars and amounts and varieties of crops to be grown, and changes in other management strategies such as sowing dates and irrigation methods. Summer crops (e.g., maize and cotton) and winter crops (e.g., wheat) were analyzed separately and in a unified annual strategy comparison.

Results from the case study conducted in Phase II are represented in Figure 4. Analysis of price data for cotton showed that over the last 30 years, it has significantly outperformed alternative crops such as maize, sorghum, soybeans, sunflowers and wheat on a revenue per feddan basis. If wheat were to be phased out because of the conflicting soil needs (wheat cannot be grown directly following cotton), current annual farm revenues would be increased by displacing the usual pattern of growing maize followed by growing wheat with growing cotton only.

If farm income were the primary consideration in the selection of strategies, the recommendation coming out of the TEAM analyses would be to shift to growing cotton (see figure 4). All of the information indicates that under climate change, growing incrementally more cotton could have strong economic benefits: cotton productivity

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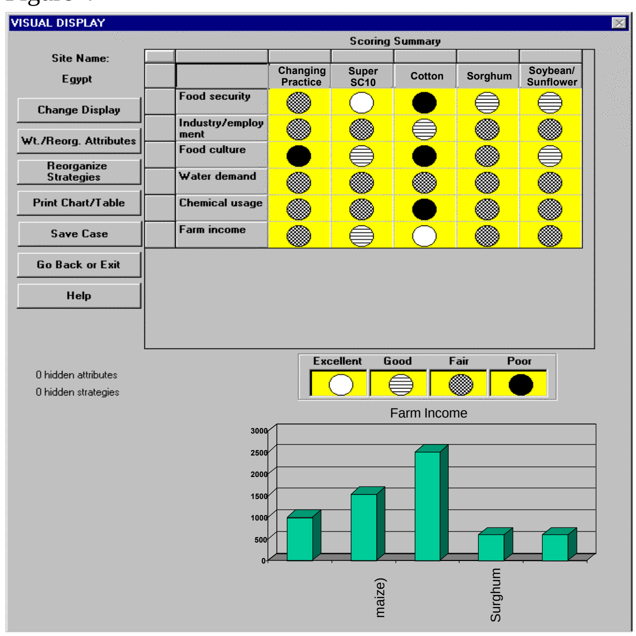
2 Tsuji, et al., 1995.

3 General Circulation Models (GCMs) used were Goddard Institute for Space Studies (GISS), General Fluid Dynamics Laboratory (GFDL), United Kingdom Meteorological Organization (UKMO) and Canadian Climate Center Model (CCCM). For descriptions of these and other GCMs, see IPCC(1996) and IPCC (1998).

may not only increase relative to other major crops, but it may increase absolutely; cotton prices are very strong and it appears possible that they will remain strong in a hotter future climate since cotton is one of the best textiles for use in hot environments; and cotton production also involves more jobs, both in the agricultural sector, and in the textiles industry that can expand with cotton growth. However, other criteria confounded the decision process and it was the role of TEAM to aid in elucidation of research members' values and to build consensus around those values. Minimizing water usage while maximizing farm income was determined to be important. Food security, important in the Phase I analysis, remained important. To a lesser extent, chemical usage was also determined to be important. If these other criteria were emphasized over farm income, then the most attractive strategy would be to grow a combination of the cotton and the super SC10 (maize) crops over the soy/sunflower and sorghum.

These results are reflected in the first recommendation: improve wheat and maize cultivars and continue as normal. The second and third recommendations were to: shift

Figure 4



from maize to cotton and use more winter crops to replace some wheat; or shift to a mix of cotton/sunflowers in the summer and continue to grow an improved wheat cultivar in the winter to the extent feasible, while using winter crops in those areas that can no longer support wheat due to an increase in cotton production. These last two recommendations are based on emphasizing farm income over the other criteria.

One lesson learned from this analysis is that Egypt may be paying heavily for food security, given that it appears to be holding back on cotton production so that more wheat can be grown domestically. Looking at a hotter future, the arguments for more cotton may be enhanced: wheat prices may decline on a global basis whereas income from cotton may be enhanced due to 30% productivity increases projected by the crop models and possible growth in demand with climate change.

More work needs to be done before recommending a major shift toward cotton. The participants in Phase II of the analysis recommended that a third phase be conducted with TEAM that would incorporate research on expanding the cotton supply and the effect this action would have on cotton prices. Any shift toward cotton would need to be phased in carefully and should involve active assessment of potential price effects.

Participants also recommended that analyses be conducted to estimate the water demand requirements for different strategies, as well as any associated changes in chemical usage. Differences of opinion about the importance of each criterion need to be resolved in the next phase, and further research may help to resolve some of these differences. Although cotton performs well economically, it is a controversial recommendation.

A further refinement recommended by participants was to examine annual and/or bi-annual cycles of the best summer and winter options that are mutually compatible with principles of crop rotation. Results of such analyses would be useful and timely -- the policy environment within Egypt has made recommendations arising from the TEAM analysis more politically feasible, particularly recommendations that call for switching crops. A recent policy of crop liberalization allows farmers the possibility of adapting to more suitable and profitable crops in each area.

4.3 Comments on the contributions of TEAM

The results of these analyses show the important role TEAM can play in focusing research throughout the decision process to develop more efficient, effective and robust recommendations. Because of the use of TEAM in the initial stages of this case study, further research using crop models and historical analysis provided quantitative results that were sometimes not intuitive and were needed for more informed decision making.

Throughout this process, individuals participating in the case study emphasized the importance of the transparency of the results. The importance of transparency became apparent in a number of ways: Phase I analyses were examined by those who participated in Phase II and the transparency of the underlying assumptions were critical to understanding how and why particular strategies outperformed others; communication about assumptions was important among various members of the analytic teams in both phases of the case study, especially where expertise might provide differing viewpoints about performance of strategies; and communication of results and recommendations to government officials would require transparency in order to convince the government of the validity of the recommendations, especially where results may be contradictory to current national policy.

Multiple disciplines were required to participate in the decision making process from the beginning. Because of the involvement of people from different backgrounds, the research agenda for the intervening period between phases of the case study addressed the variety of information needs discovered in the first phase. The involvement of representatives of the Egyptian government were critical to understanding the feasibility of different options and for providing an overall sense of the importance of different criteria in the policy making process.

This case study revealed that the criterion considered of primary importance in developing agricultural policy -- national security -- may have led to lower economic returns. This may be an acceptable tradeoff providing the government made its decision with full knowledge of the priorities implicit in their decision. The TEAM framework makes this tradeoff clear. In the future, the Egyptian government may decide to change its agricultural policy, or it may decide to continue with current practices, depending on their determination of the importance of domestic production of wheat. However, if climate change threatens the ability of Egypt to continue producing wheat, this tradeoff is all the more important to understand.

Finally, group processes proved critical to enumerating options for the agriculture sector and eliciting values. Differing values led to different recommendations for crop selections in the second phase of analysis, especially with respect to economic performance, pointing to the need for further work to assess performance of strategies along other criteria. With TEAM, not only was research focused to provide the most useful results for the decision making process, but a foundation was built on which values were understood and consensus could be reached to make final recommendations.

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